NAVAL AIR DEVELOPMENT CENTER

Warminster, Pennsylvania

NADC-CS-7110 28 October 1971

Portable Detector of Low Amplitude Electrocardiographic Activity

Naval Air Systems Command
Task ZFXX212001
(RF-2)

DEPARTMENT OF THE NAVY
NAVAL AIR DEVELOPMENT CENTER
WARMINSTER, PA. 18974

Crew Systems Department

NADC-CS-7110

Portable Detector of Low Amplitude Electrocardiographic Activity

Naval Air Systems Command
Task ZFXX212001
(RF-2)

Prepared by:

George E. Bergey

Russell D. Squires, M.D.

William J. Miller

Approved by:

Harald J. von Beckh, M.D.
Research Director
Crew Systems Department

Released by:

L. H. Blackburn, CAPT, MC, USN
Director
Crew Systems Department

SUMMARY

A portable instrument is described which quickly indicates the presence or absence of myocardial activity. The instrument consists of two probes connected by a flexible retractible coiled cable. The stainless steel tips of each probe constitute the input connections of the enclosed circuitry and, in use, are placed in contact with the skin on the precordium. The electrical signal present between probe tips is processed by a network of filter, trigger, and logic circuits, the result of which is a bright flash of a light-emitting diode for each QRS complex present at the input.

Because of its simplicity of operation, this device could easily be used by paramedical personnel as well as physicians in a variety of emergency situations.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

The assistance of Mr. R. J. Zabelicky in the construction of the prototypes described and the secretarial assistance of Mrs. Jane Fiero is gratefully acknowledged.

INTRODUCTION

The electrocardiogram (EKG) can be detected for some time after rhythmic myocardial activity cannot be readily ascertained by auscultation or palpation even under ideal conditions. Regular electrocardiographic activity may continue for more than a minute after intra-arterial pressure recordings indicate a sudden loss of effective pulsations (1). A quick objective decision as to the presence or absence of rhythmic myocardial electrical activity often becomes a significant factor in the triage of severe mass casualties either military or civilian.

The instrument described is a miniature, battery-powered, solid-state device which indicates the presence of an EKG by means of a flashing light and/or an audible signal in a miniature earphone. Because of its simplicity of operation, this instrument could easily be used by paramedical personnel as well as physicians.

INSTRUMENT DESCRIPTION

A prototype low-level EKG indicator has been constructed of discrete components. Physically the instrument consists of two probes, each 8 inches long by 1-1/4 inches diameter, connected by a flexible retractable coiled cable. The stainless steel tips of each probe constitute the input connections of the enclosed circuitry, a block diagram of which is shown in Fig. 1. Figure 2 is a complete schematic diagram of the circuit. In use, the probe tips are placed in contact with the skin on the precordium. The voltage appearing between these two probe tips consists of a low amplitude (0.3 to 2.5 millivolts peak-to-peak) EKG signal synchronous with heart action and "noise" of varying degrees of severity. The noise signal arises from a number of sources with some of the higher amplitude components coming from 60 Hertz power line interference, low frequency interference from "electrode" (probe tip) movement, and broadband interference from muscle tension (electromyogram). For simplicity of operation, the instrument uses only two input "electrodes", rather than the three normally employed in recording EKG's with a differential amplifier. Extensive filtering, rather than common-mode signal rejection is utilized in processing the input signal.

Referring to Figs. 1 and 2, the signal enters via the two input probes, one of which is connected to system common. Following the input coupling capacitor, Q1 and Q2, low-leakage complementary bipolar transistors connected in a diode clipper configuration, limit the signal to approximately ±600 millivolts to protect the input junction field-effect transistor (FET), Q3. The input stage provides a voltage gain of approximately 15 above the cutoff frequency of 6 Hertz (-3 dB), determined by the input capacitor and the FET gate resistor. This resistor also determines the input impedance (2.7 MΩ).

The QRS complex of the signal is then filtered out by means of an active filter consisting of a high gain amplifier, Q4, Q5, Q6, with a twin-T feedback network. The low-pass characteristics of this filter approximate those of a third-order Butterworth above about 20 Hz. First order high-pass filtering in this filter is provided below about 11 Hz by the 0.1 μF coupling capacitor between Q4 and Q5.

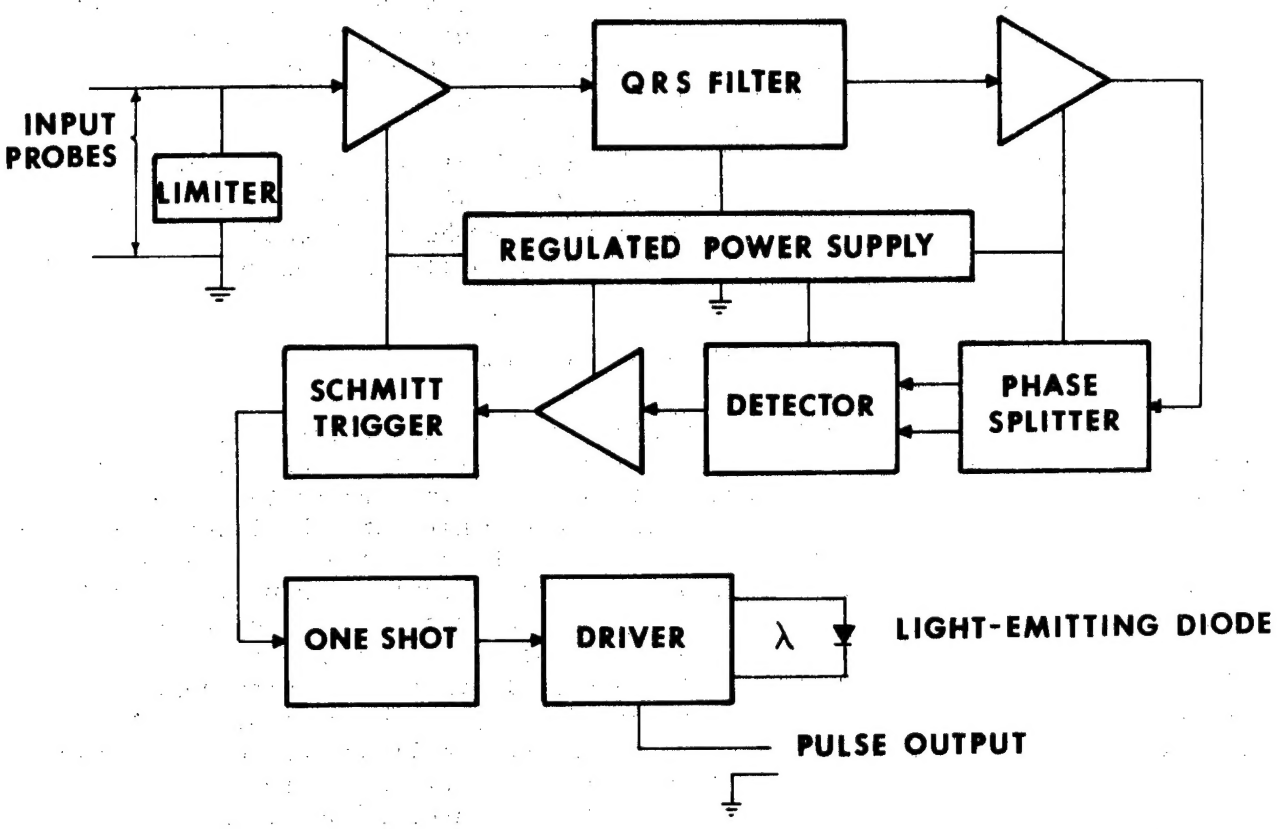

Figure 1. Block diagram of the portable EKG detector.

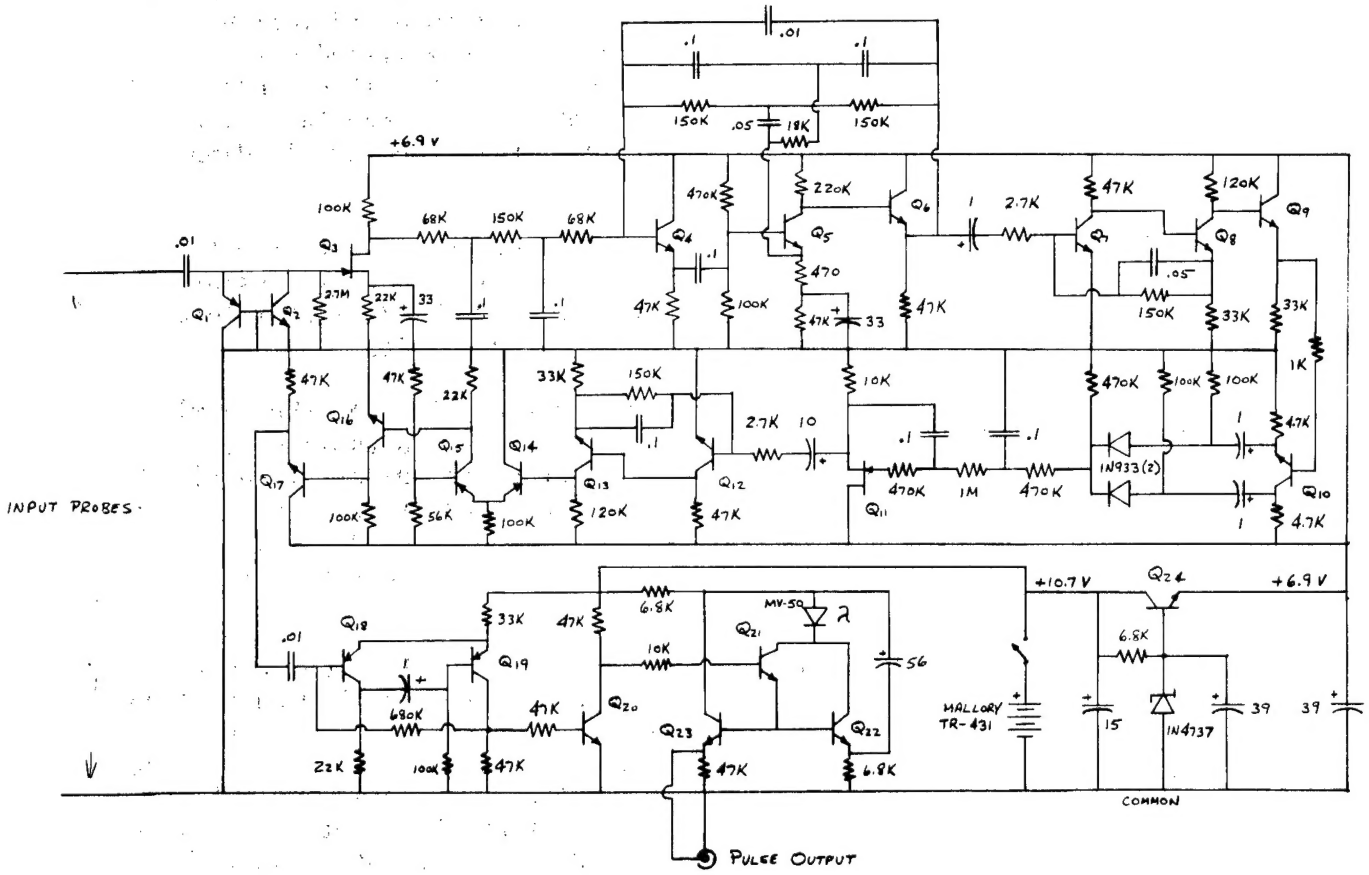

Figure 2. Complete schematic diagram of detector circuit. All NPN transistors: 2N4124, all PNP: 2N4126, Q3 and Q11: 2N4220.

This filtered signal is then amplified by Q7 and Q8 with additional bandpass filtering over the same frequency range provided by the 1 μF input coupling capacitor and the 0.05 μF capacitor in the feedback loop. Within the passband, the voltage gain of this amplifier is approximately 150. An emitter follower, Q9, is used to provide a low impedance driving point for Q10, a phase splitter. So that no polarity is associated with either input probe, the signal and a 180° inversion of the signal are taken from the emitter and collector of Q10 through coupling capacitors to two 1N933 germanium diodes for full-wave rectification. Detection of amplitude modulation of this rectified waveform, due to the QRS complex, is accomplished with a two-stage filter with a time-constant of approximately 50 milliseconds. This technique eliminates the possibility of sustained 60 Hz triggering. The high input impedance of source follower, Q11, prevents excessive loading of this detector filter.

The resultant pulses corresponding to the QRS complexes are first amplified by Q12 and Q13 and then sharpened by a Schmitt trigger consisting of a comparator, Q14 and Q15, and switch Q16. The threshold trigger level is established by the voltage divider biasing the base of Q15.

Another emitter follower, Q17, then couples the output of the Schmitt trigger, consisting of pulses of equal amplitude, to a monostable multivibrator (one-shot), Q18 and Q19. This circuit produces pulses of equal duration as well as amplitude. The pulse duration is determined by the base resistor of Q19 and the coupling capacitor between Q18 and Q19. For the values shown, pulse duration of approximately 100 milliseconds are produced.

These pulses drive another transistor switch, Q20. Between output pulses from Q20, the 56 μF capacitor in the output driver is charged through the 6.8 K series resistor in the positive power supply line. An output pulse from Q20 causes Q21 and Q22 to conduct, thus discharging this capacitor through the Monsanto MV-50 light-emitting diode (LED) and causing the LED to blink brightly once for each QRS complex present at the input. An emitter follower, Q23, driven by Q21, presents 5 volt pulses at an output jack for optional display or recording as desired. After the LED fires, the storage capacitor recharges through the series resistor.

Using a LED for an indicating device has the advantages of providing higher brightness for a given current drain as well as a much longer life span in comparison with an incandescent bulb. Although the peak current drawn by the LED when it lights is 15-20 milliamperes, by using the capacitive-discharge system shown the drain on the system power supply is reduced to an average of 1.2 milliamperes continuous drain (including the entire circuit) with peak-to-peak variations of about 40 microamperes occurring during a typical LED firing cycle. It is necessary to minimize large, fast fluctuations in current drain to avoid variations in the power supply voltage used to power the initial high-gain stages (Q3-Q13). Such voltage variations, if allowed to occur would appear as QRS signals to the Schmitt trigger and

oscillations would develop due to feedback along the power supply lines. A regulated power supply, consisting of a Zener diode (1N4737), series transistor Q24, and filter capacitors, is used to power all circuitry preceding the one-shot.

In addition to, or instead of, the blinking LED, an audio oscillator driving a speaker or earphone could be turned on and off to provide an audible indication of QRS complexes.

RESULTS

Figure 3 illustrates the method used to evaluate the ability of the instrument to detect QRS complexes superimposed on varying degrees of "noise". This test circuit consists of a conventional EKG system employing three electrodes and a differential amplifier with a voltage gain of 500, a sine wave generator, and a network that permits mixing the outputs of the two. By placing the two input probes across the resistor at B as shown in Fig. 3, the minimum QRS amplitude required to reliably trigger the detector can be determined for various conditions of "noise" or interference.

The data shown in Fig. 4 was collected by adjusting the output level of the EKG amplifier shown in Fig. 3 to a given QRS amplitude, ranging from 0.2 to 2.0 millivolts. The amplitude of the sinusoidal interference signal, superimposed on the EKG signal at point B, was then adjusted to be the maximum that would not cause erroneous triggering of the detector circuit on the QRS complexes. For example, with a peak-to-peak QRS amplitude of 1 millivolt, the detector will reliably trigger once for each QRS for superimposed 60 Hz interference signals of 42 millivolts or less. Above that amplitude, the ability of the circuit to distinguish QRS complexes is impaired.

The linearity of the three curves in Fig. 4 above a QRS amplitude of 200 microvolts suggests plotting a continuous spectrum of the maximum amount interference tolerable by the detector. This data, shown in Fig. 5, was also collected with the method shown in Fig. 3. The unit will accurately detect QRS complexes superimposed on interference levels which fell below the ratios of interference-to-QRS amplitude indicated by the curve. Thus for example, the instrument is capable of detecting QRS complexes when superimposed noise at either 1 Hz or 60 Hz is less than about 31 dB greater in amplitude than the QRS.

Figure 6 illustrates three examples of the operation of the unit.

In Fig. 6a a QRS signal of 1 millivolt peak-to-peak amplitude is barely discernable on 60 Hz interference of about 30 millivolts peak-to-peak amplitude. (This corresponds to a "interference-to-QRS" ratio of about 29.5 dB). As shown by the regularity of the output pulses, the detector was triggered reliably.

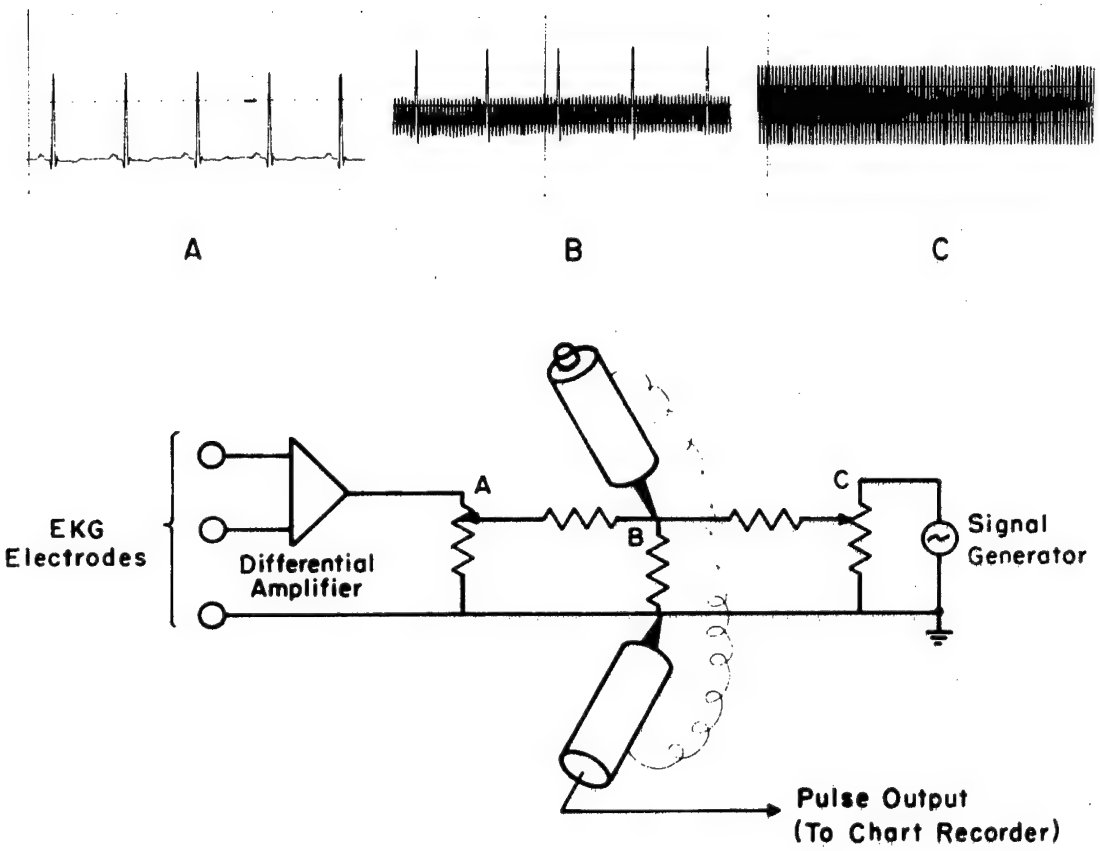

Figure 3. Schematic diagram of the method used for bench-testing the ability of the EKG detector to reject varying degrees of "noise". The lettered chart recordings represent typical waveforms at the correspondingly lettered points on the schematic with B being the test input to the EKG detector.

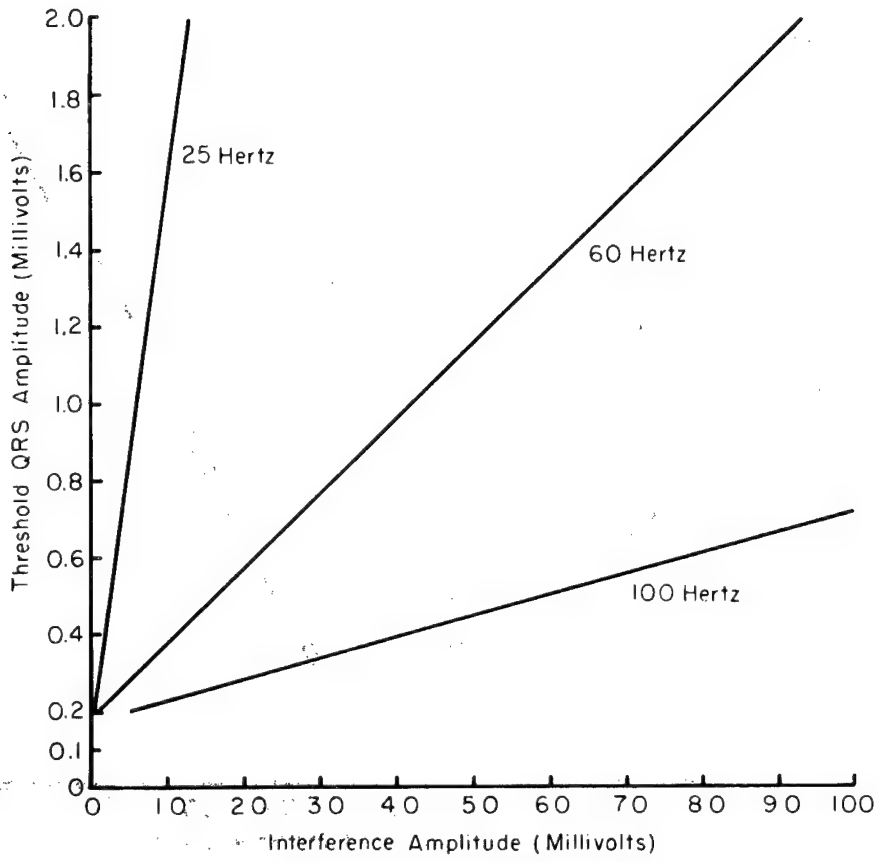

Figure 4. Minimum peak-to-peak QRS amplitude required to reliably trigger the detector as a function of the peak-to-peak amplitude of a superimposed interference signal. Curves are shown for sinusoidal interference signals at three different frequencies.

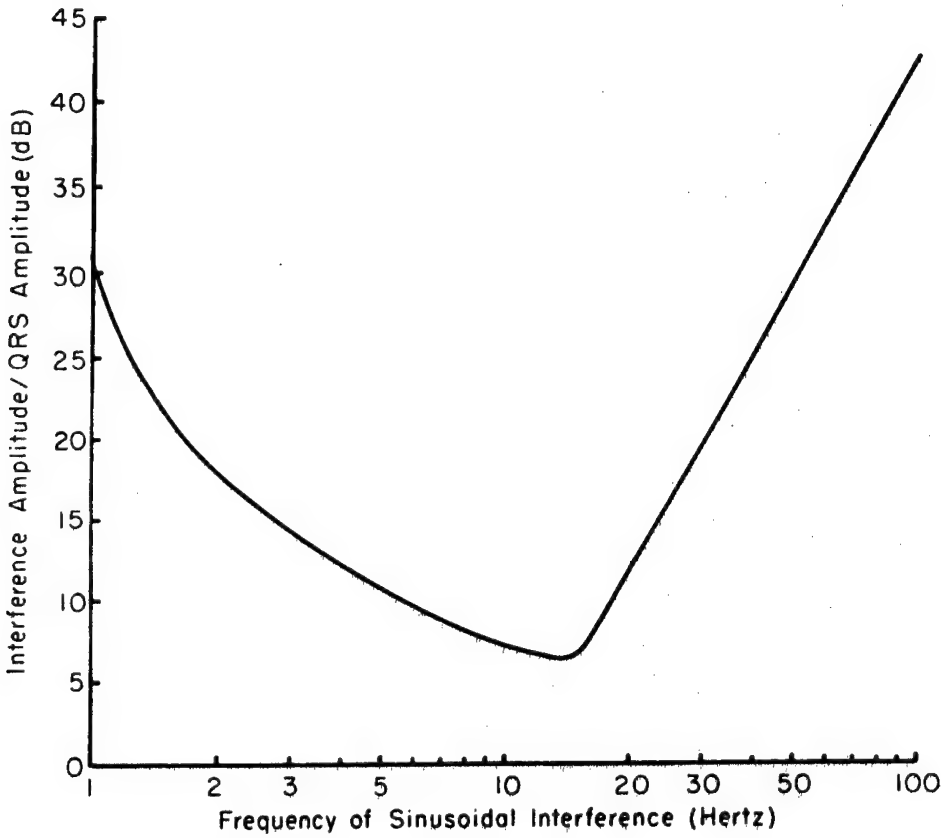

Figure 5. Continuous spectrum of the maximum amount of superimposed sinusoidal interference that the detector is capable of rejecting. The area under the curve indicates those levels of noise relative to the amplitude of the QRS complexes, at which the instrument will reliably operate.

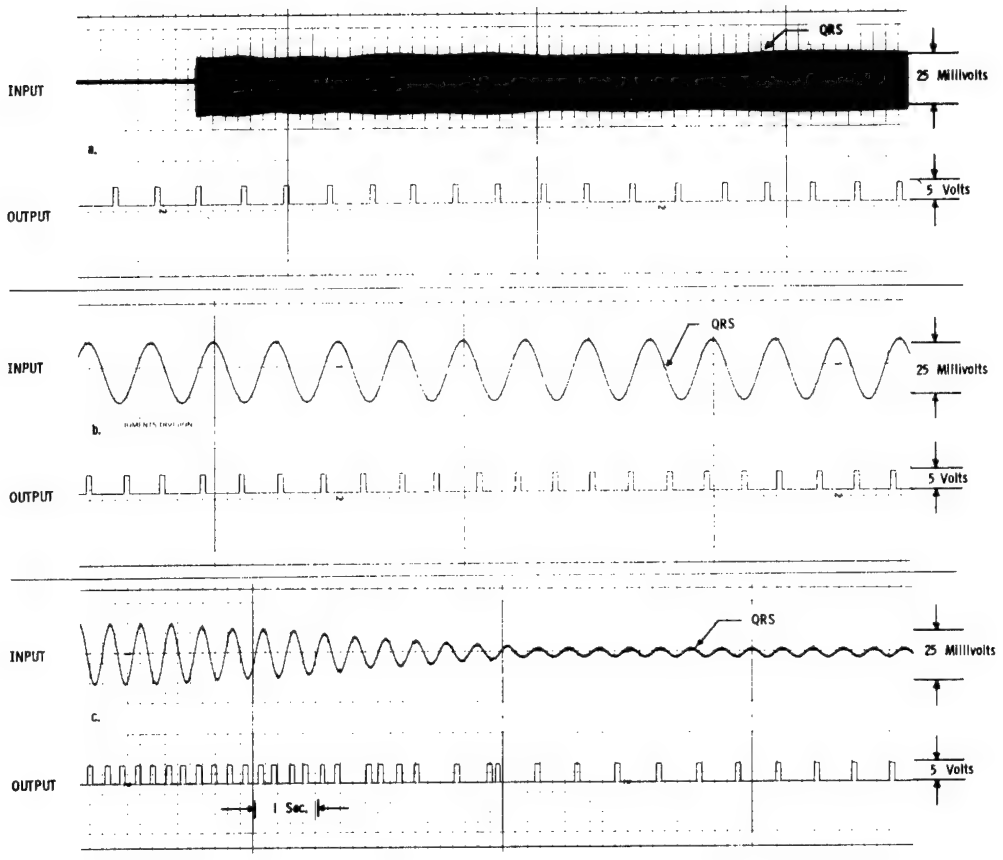

Figure 6. Examples of the detector's ability to reject interference. A 1 millivolt QRS signal is superimposed on:

(a) 30 millivolts of 60 Hz interference
(b) 30 millivolts of 1 Hz interference
(c) Varying amount of 2 Hz interference (Note erratic triggering at higher amplitudes).

Figure 6b shows the ability of the detector to reliably detect QRS complexes with a comparable level of 1 Hz interference.

Figure 6c illustrates the inability of the detector to extract the QRS from 30 millivolts of 2 Hz interference. At that level, the detector is triggered by the 2 Hz sine wave, rather than by the superimposed QRS complexes. As the amplitude of the interfering signal is decreased from 18 to 8 millivolts, the triggering is erratic; below 8 millivolts the unit triggers on the QRS complexes. This level of performance is in concurrence with the graph in Fig. 5.

Figure 7 illustrates examples of "noise" that is capable of causing unreliable triggering of the QRS detector.

Figure 7a shows that even high levels of 60 Hz signals cannot cause sustained triggering of the unit as long as the amplitude is not rapidly modulated. For example, in Fig. 7a the amplitude of a high amplitude 60 Hz input signal is slowly varied, with no resultant extraneous output pulses. If this signal is rapidly varied in amplitude, however, as in Fig. 7b, the unit will be triggered.

Figure 7c illustrates sustained triggering of the unit for high amplitude input frequencies between 5 and 22 Hz, the triggering is erratic; above about 22 Hz triggering does not occur.

DISCUSSION

Figure 8 illustrates the operation of the low-level EKG detector. Its portability and ease and speed of operation should make this instrument useful in a number of military and civilian applications including in hospital emergency rooms, on ambulances, helicopters and other emergency vehicles and in the field or on house-calls. The instrument should also prove useful in evaluating the effectiveness of a defibrillator in the treatment of ventricular fibrillation, a procedure which often destroys or saturates the input stages of conventional EKG monitoring equipment.

Further reduction in the size of the instrument would probably be useful to facilitate its being carried in a pocket or instrument bag. Presumably the use of integrated circuits, rather than the discrete components used in the construction of the particular unit described, would enable a considerable reduction in size.

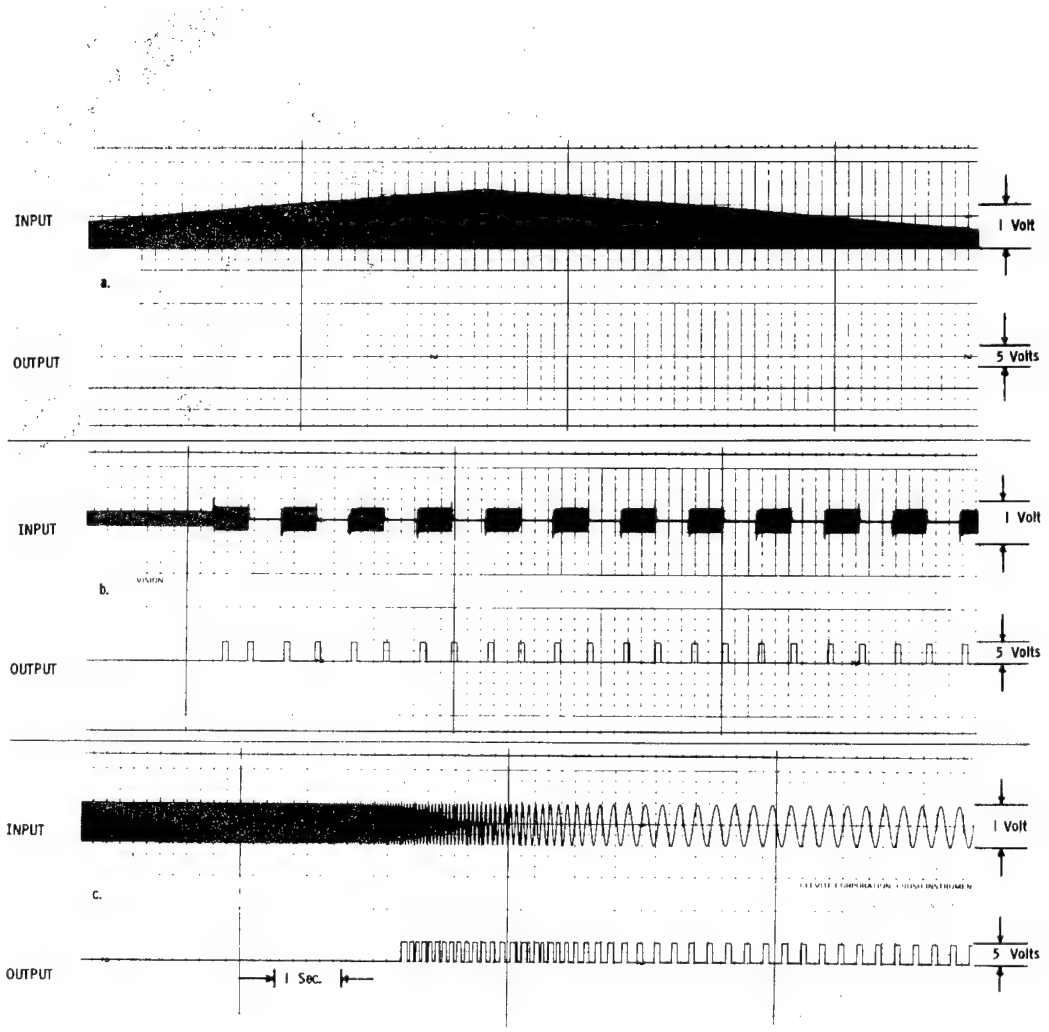

Figure 7. Examples of "interference" that can cause unreliable operation of the detector.

(a) 60 Hz interference slowly varying between 500 and 1350 mv p-p (No faulty triggering)
(b) 500 mv p-p, 60 Hz interference turned on and off at 1 cycle per sec.
(c) 1 volt p-p interference swept in frequency from 60 Hz to 3.5 Hz.

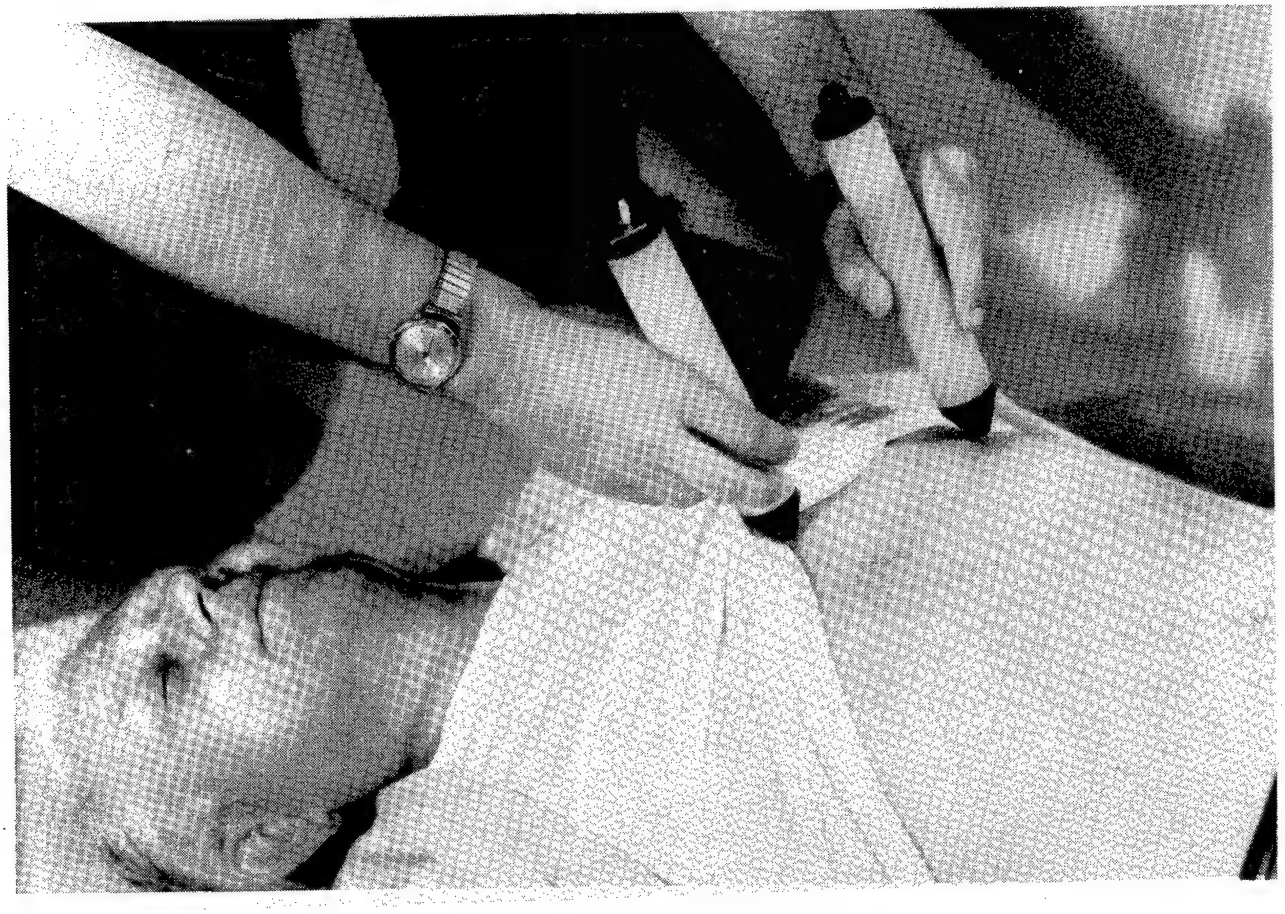

Figure 8. In use, the probe tips of the instrument are placed in contact with the skin on the precordium. The light-emitting diode on the end of one probe flashes once for each QRS complex detected.

REFERENCES

1. Shubin, H. and Weil, M. H. Practical consideration in the management of shock complicating acute myocardial infarction. Am. J. Cardiol. 26: 603, 1970.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (*Corporate author*)

Crew Systems Department
Naval Air Development Center
Warminster, Pa. 18974

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

PORTABLE DETECTOR OF LOW AMPLITUDE ELECTROCARDIOGRAPHIC ACTIVITY

4. DESCRIPTIVE NOTES (*Type of report and inclusive dates*)

Phase Report

5. AUTHOR(S) (*First name, middle initial, last name*)

George E. Bergey
William J. Miller
Russell D. Squires

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
28 October 1971	13	1

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO ZFXX212001 (RF-2)	NADC-CS-7110
c.	9b. OTHER REPORT NO(S) (*Any other numbers that may be assigned this report*)
d.	

10. DISTRIBUTION STATEMENT

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE: ITS DISTRIBUTION IS UNLIMITED.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

A portable instrument is described which quickly indicates the presence or absence of myocardial activity. The instrument consists of two probes connected by a flexible retractible coiled cable. The stainless steel tips of each probe constitute the input connections of the enclosed circuitry and, in use, are placed in contact with the skin on the precordium. The electrical signal present betweel probe tips is processed by a network of filter, trigger, and logic circuits, the result of which is a bright flash of a light-emitting diode for each QRS complex present at the input. Because of its simplicity of operation, this device could easily be used by paramedical personnel as well as physicians in a variety of emergency situations.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Electrocardiogram						
2. Casualties						
3. Pasteless electrodes						
4. Asystole						
5. Ventricular fibrillation						

DISTRIBUTION LIST (Cont'd)

American Institutes for Research, Pittsburgh ---------- 2
Aviation Medicine Research Lab. (Dr. Billings), Columbus ------ 1
Biological Abstracts, Philadelphia ---------- 1
Cornell Aeronautical Lab. (Library), Buffalo ---------- 1
Countway Library of Medicine, Boston ---------- 1
Drexel University (Biomedical Engrg.), Philadelphia ---------- 2
University of Illinois, Chicago ---------- 1
Indiana University, Indianapolis ---------- 1
Library of College of Physicians of Philadelphia ---------- 1
Lovelace Foundation, Albuquerque ---------- 1
Ohio State University, Columbus ---------- 1
University of Pennsylvania, Philadelphia ---------- 1
John B. Pierce Foundation Lab., New Haven ---------- 1
Presbyterian-Univ. of Pa. Medical Center, Philadelphia -------- 1
University of Southern California, Los Angeles ---------- 1
Temple University Hospital (Dr. Kern), Philadelphia ---------- 1
University of Washington, Seattle ---------- 1
Wayne State University, Detroit ---------- 1
Wrightsville Marine Bio-Med. Lab., Wilmington, N.C. ---------- 2
University of California, Davis, Calif. ---------- 1

David Clark Co., Worcester, Mass. ---------- 1
Convair Div. of General Dynamics, San Diego ---------- 1
General Electric Co., Philadelphia ---------- 2
Grumman Aerospace Corp., Bethpage, N.Y. ---------- 1
Hageman Consulting Services, Fort Worth ---------- 1
Lockheed-California, Burbank ---------- 1
North American Rockwell Corp., Los Angeles ---------- 1
Republic Aviation Div. (Engrg. Library), Farmingdale, N.Y. ---- 1
Republic Aviation Div. (Life Sciences), Farmingdale ---------- 1
Vought Aeronautics (Human Factors), Dallas ---------- 2
Webb Associates, Yellow Springs, Ohio ---------- 1

Dr. Carl C. Clark, Baltimore ---------- 1
Dr. R.H. Edgerley, Hazlewood, Mo. ---------- 1
Dr. Herbert Shepler, Paradise Valley, Arizona ---------- 1
Dr. F. Kirk Smith, Moorestown, N.J. ---------- 1

CREW SYSTEMS DEPARTMENT

DISTRIBUTION LIST

DDC, Alexandria, Va.	2
National Library of Medicine, Bethesda, Md.	1
Bureau of Medicine and Surgery (Code 71)	3
Bureau of Medicine and Surgery (Code 713)	1
Bureau of Medicine and Surgery (Code 7113)	1
Bureau of Medicine and Surgery (Code 52)	1
Naval Aerospace Medical Research Lab. (Code L23) Pensacola	1
Naval Aerospace Medical Research Lab. (Physiol.) Pensacola	2
Naval Training Device Center, Orlando	2
NMRI (Tech. Ref. Library), Bethesda	1
Naval Submarine Med. Center (Library), Groton, Conn.	1
NAVAIRSYSCOM (AIR-531)	2
NAVAIRSYSCOM (AIR-604)	2
NAVAIRSYSCOM (AIR-5311G)	1
Navy Med. Neuropsychiatric Research Unit, San Diego	1
Naval Safety Center, Norfolk	1
Naval Air Test Center, Patuxent River	1
ONR (Code 107), Arlington	1
Naval Research Lab. (Library), Washington, D.C.	35
FAA (AC-100), Oklahoma City	1
FAA (AC-922), Oklahoma City	1
Dept. Transportation Library (FAA), Washington, D.C.	2
6570 AMRL (SCI-L) Library, Wright-Patterson AFB	1
HQ, USAF (Col. R.A. Yerg), Washington, D.C.	1
USAF SAM (SCL-4), Brooks AFB, Texas	1
USAF SAM/RAT, Brooks AFB, Texas	1
Air University Library, Maxwell AFB, Alabama	1
AFFTC (SGU), Edwards AFB, Calif.	1
HQ, TAC (SG), Langley AFB, Virginia	1
Aerospace Pathology Branch, Washington, D.C.	1
Tech. Support Directorate (Librarian), Edgewood Arsenal	1
USA Natick Labs. (Tech. Library), Natick, Mass.	1
USA Manpower Resources R&D Ctr., Arlington (Dr. Dusek)	1
USA Medical Research Lab., Fort Knox	1
NASA-Langley Research Center, Hampton, Va.	2
NASA-Lewis Research Center (Library), Cleveland	2
NASA-Manned Spacecraft Center (E.L. Hays), Houston	2
Science & Tech. Div., Library of Congress	1
National Institues of Health (Library), Bethesda	1
National Research Council (Med. Records)	1
Space Science Board, Nat'l Acad. Sci., NRC	2
U.S.A.A.R.L., Fort Rucker, Ala. (Scientific Adviser)	1